Effect of Offset Jetties on Tidal Inlet Flood Flow

By

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ABSTRACT

Tidal currents at inlets protected by jetties exhibit characteristics of jetlike flows. For flood tide, the planform geometry of parallel inlet jetties appears to be a major factor influencing the flood flow distribution across the inlet channel. Equal-length jetties tend to direct the majority of the flood flow down the middle of the channel, but if the jetties have unequal seaward lengths, the flow is directed to one side of the channel. This asymmetric flow pattern may cause scouring adjacent to the toe of the longer jetty and shoaling on the opposite side of the channel, forcing navigation away from the channel centerline. This paper presents measurements acquired at Shinnecock Inlet, Long Island, New York, that support the existence of jetlike flood flows predicted to be induced by offset jetties.

Keywords: Inlets, tidal inlets, structured inlets, jetties, entrance channels, flood tide, inlet scour, jet flow, Shinnecock Inlet

INTRODUCTION

MANY TIDAL INLETS HAVE BEEN STABILIZED by construction of single or dual-jetty systems that typically are aligned perpendicular to the general shoreline orientation. The jetties prevent inlet migration, and in most cases make it easier to maintain navigation channels linking the ocean with the back bay harbor facilities. In stabilizing inlets with structures, engineers and planners must anticipate and deal with problems such as erosion of the adjacent beaches, scour holes that threaten jetty stability, hazardous navigation conditions during peak tidal flows and high waves, and adequate circulation in environmentally sensitive back bay areas.

Parallel jetties act like flow nozzles as the tidal exchange is forced through the entrance channel during ebb and flood tide. In many cases this funneling creates velocities sufficient to sweep sediment from the entrance channel, thereby reducing channel maintenance dredging. The similarity of dual-jetty inlet systems to jet flow through a nozzle has been recognized by coastal engineers, and conventional inviscid and turbulent jet theories have been applied to explain and quantify local flow characteristics at structured tidal inlets (e.g., French 1960, Ozsoy 1977, Joshi 1982, Joshi and Taylor 1983).

This article examines the jetlike flow pattern that occurs during flood tide where the seaward extent of one jetty is different than the other, a condition referred to as *offset jetties*.

Flood Flow Patterns at Dual-Jetty Inlets

The flow patterns for dual-jetty tidal inlet channels during peak flood flow appear to be controlled to a large extent by the geometry of the inlet jetty structures. The two sketches in Figure 1 compare qualitatively the different flood flow patterns developed by equi-length and offset jetty systems.

Figure 1(a) illustrates flood flow if two parallel jetties have the same seaward length. At peak flood when the inlet experiences maximum discharge, flow separation (represented by dashed lines) occurs at the inlet entrance structures, concentrating the majority of the discharge toward the center of the channel. If the flow were frictionless, all of the discharge would remain concentrated between the dashed lines. Flow adjacent to the jet would remain motionless under this frictionless (inviscid) flow assumption. However, this is not the case because strong shearing occurs at the jet boundary, and lateral turbulent flow entrainment occurs at both sides of the flood jet. As fluid is entrained into the flood jet, the flow discharge distribution spreads across the channel, and peak velocities decrease in magnitude farther into the entrance. With jetties having equal seaward lengths, the strongest velocities remain near the channel centerline, and this promotes "self-scouring" of the navigation channel.

Figure 1(b) is a qualitative representation of the flood flow distribution if parallel jetties terminate with unequal lengths. In

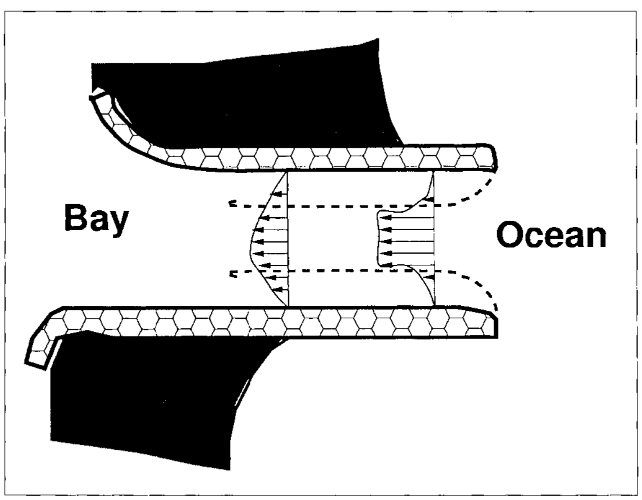

Figure 1. Flood flow discharge distributions for equal length and offset jetty systems. (a) Flood flow with equal length jetties.

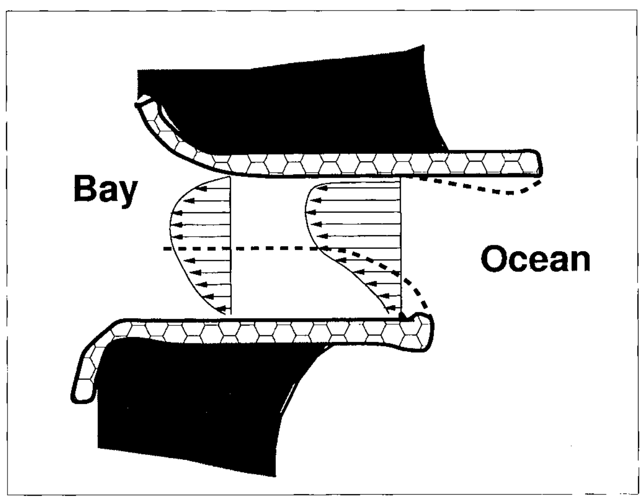

Figure 1 (b) Flood flow with offset jetties.

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this case the main flood flow enters the channel at an angle offset from the channel centerline with most flow separation occurring at the tip of the shorter jetty. (The dashed lines represent the edges of an inviscid flood jet calculated from similar nozzle geometry). At separation, the main body of the jet moves across the channel resulting in the majority of the flow being concentrated in the half of the channel closest to the longer jetty. Most of the turbulent flow entrainment occurs along the flood jet boundary out in the middle of the channel. A turbulent boundary layer also forms adjacent to the longer jetty, and the overall flow pattern resembles that of a turbulent wall jet. As the flow progresses farther into the inlet, the entrainment process and, to a lesser extent, the jetty boundary layer, spread the flood discharge distribution across the channel. The widening discharge distribution decreases maximum velocities in accordance with continuity requirements.

The asymmetric jet shown in Figure 1(b) has the potential of creating two engineering problems. First, the strong velocities can scour a trench adjacent to the toe of the jetty structure. For rubble-mound structures this could lead to toe instability and possibility slumping of the main armor layer, resulting in expensive repairs. The second problem arises because the reduced velocities along the inlet centerline may not be sufficient to maintain the navigation channel through self scouring. Shoaling of the main channel will force vessels to transit the deeper region closer to the jetty, increasing the risk of collision with the structure.

Filling any scour trench that develops and protecting the fill with a stone blanket will remove the risk of jetty toe instability and potential structure damage; but this will not alter the flow distribution which is controlled by the inlet geometry. After filling the trench, the same flood flow discharge distribution will persist through that portion of the channel, but now the cross-sectional area is reduced, resulting in increased maximum flood currents and potentially hazardous navigation conditions during peak flood flow.

Case Study: Shinnecock Inlet

Shinnecock Inlet is located in eastern Long Island in Suffolk County, near the town of Southampton, New York (Figure 2). The inlet connects the Atlantic Ocean to Shinnecock Bay, and it is the most easterly of six permanent inlets in the barrier island chain that follows Long Island's south shore. Shinnecock Inlet was formed during the Great New England Hurricane of September 1938, when high waves and a storm surge overwashed the barrier island. The morphological behavior and historic development of Shinnecock Inlet are described by Morang (1999).

Shinnecock Inlet has two parallel jetties of unequal seaward lengths as shown by the aerial photograph of Figure 3. The channel width between the parallel jetties is approximately 250m (820 ft). At maximum flood tide the total discharge entering the bay is on the order of 2,400 m^3/s (85,000 ft^3/s).

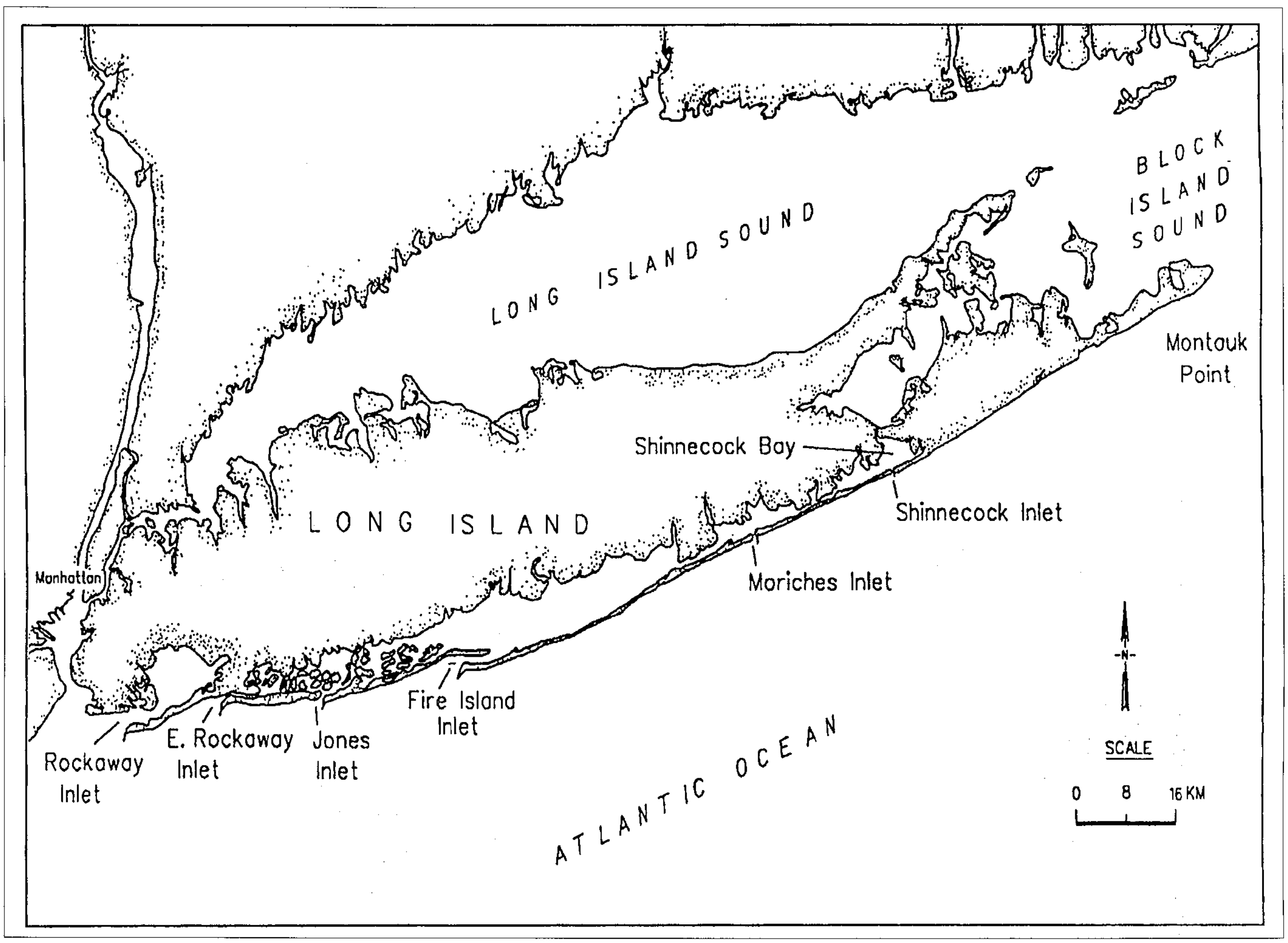

Figure 2. Shinnecock Inlet, New York, vicinity map.

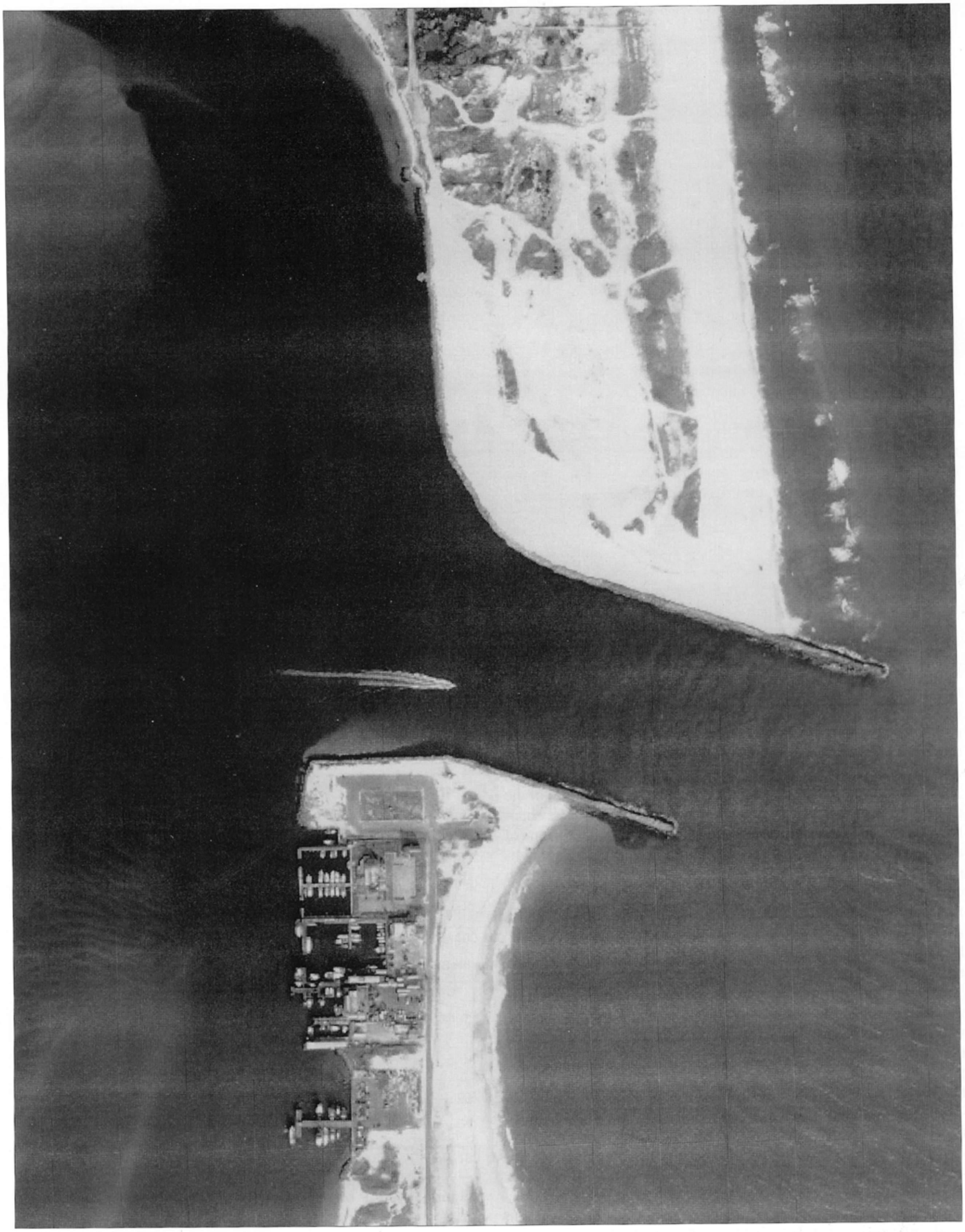

Figure 3. Aerial photograph of Shinnecock Inlet (1997).

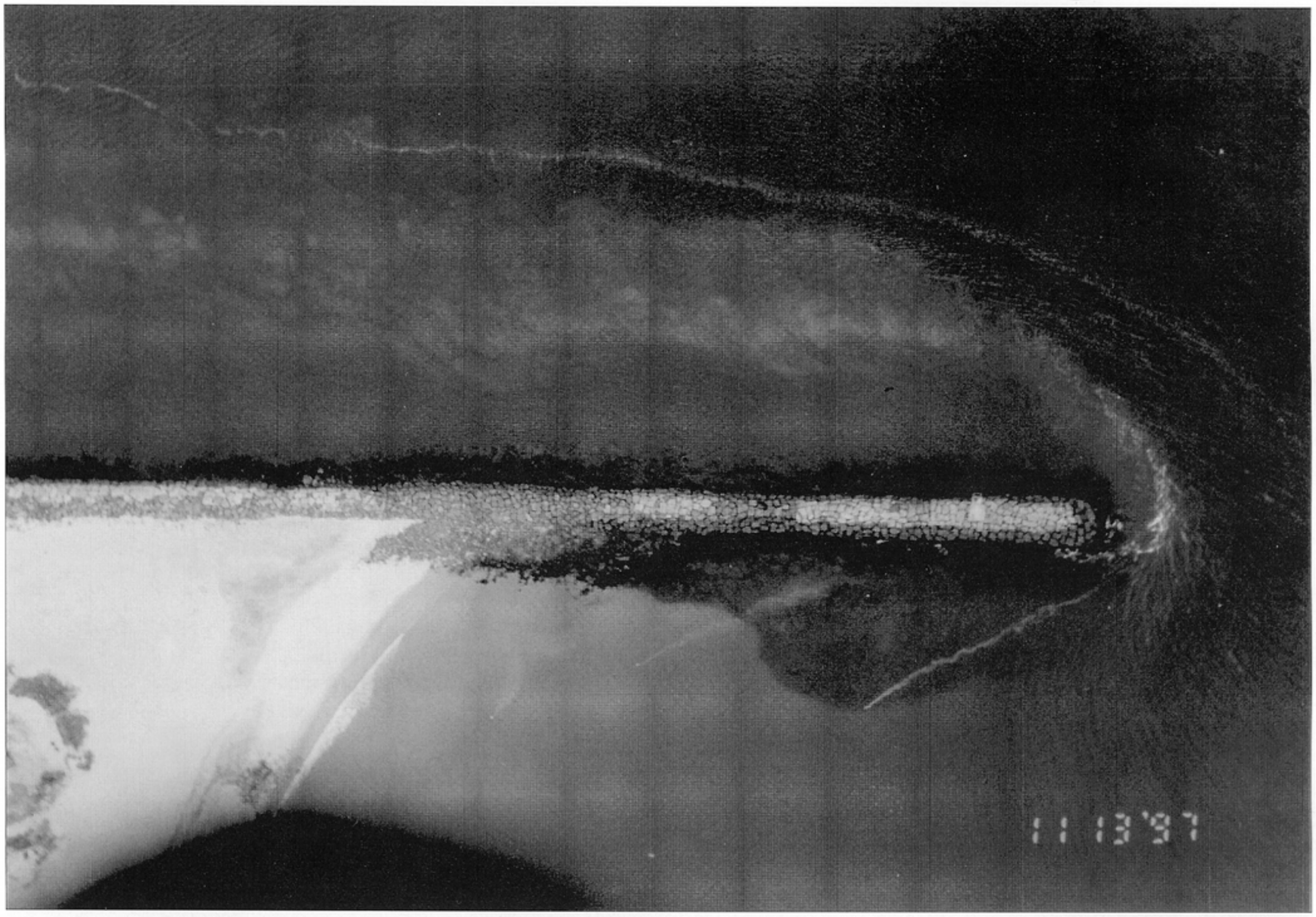

Figure 4. Dye injection at the Shinnecock Inlet west jetty.

Visual evidence of a flood jet pattern similar to the sketch in Figure 1(b) is provided by the aerial photograph of Figure 4, which shows a dye pathline extending around the short (west) jetty. Dye injected at a point located to the west (shore side) of the short jetty was carried around the jetty tip and into the inlet channel during flood tide. Notice how far the dye pathline extended into the middle of the inlet. The dye pathline corresponds roughly to the location of the dashed line shown in Figure 1(b), which represents the boundary of an ideal inviscid jet.

Flow Distribution During Maximum Flood Tide

Cross-channel flow distributions at Shinnecock Inlet were calculated based on velocity data gathered around the time of maximum flood flow on July 22, 1998. Vertical velocity profiles were measured along crosschannel transects (shown on Figure 5) using a boatmounted acoustic Doppler current profiler (ADCP). The ADCP produced velocity vectors averaged over 25-cm vertical bins. Vessel positioning was obtaining using a Global Positioning System. Each cross-channel transect line had between 30 to 45 vertical profiles recorded, and it took about 20 minutes total to profile the current velocities on the four transects shown on the plan view sketch of Shinnecock Inlet in Figure 5.

Figure 6 presents calculated discharge distributions for each inlet transect shown on Figure 5 with the landward most transect at the top and the seaward most transect at the bottom. The approximate channel centerline is shown on each plot by a

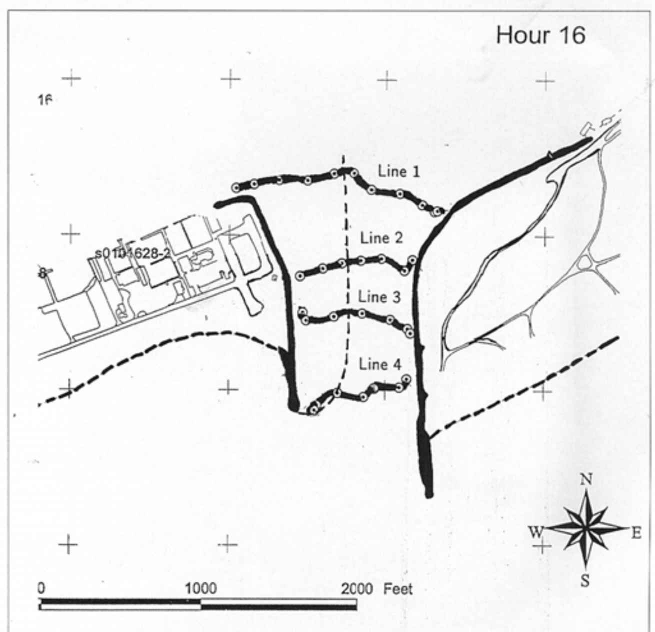

Figure 5. ADCP crosschannel velocity transects (July 1998).

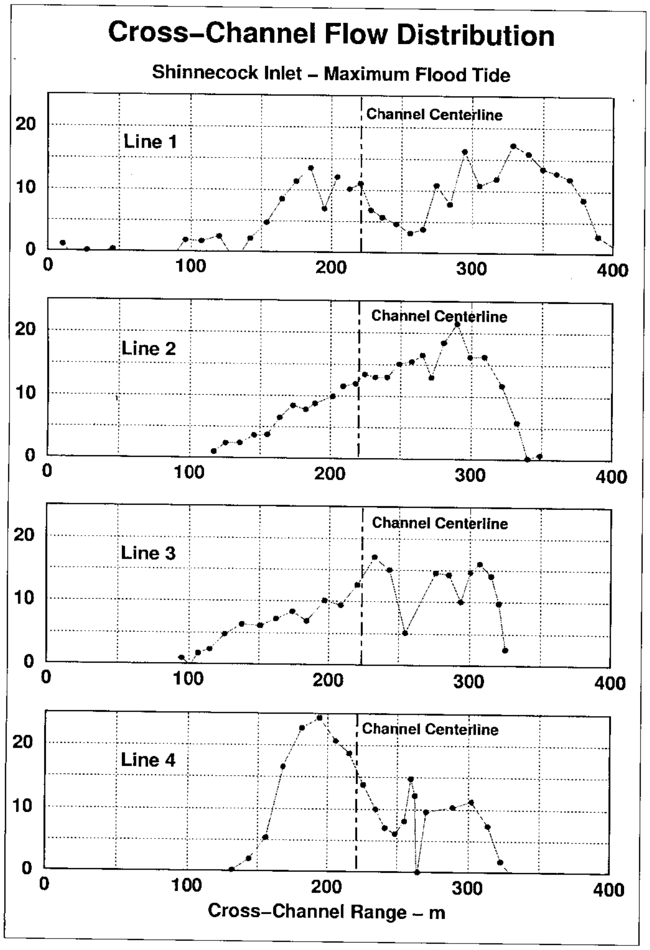

Figure 6. Crosschannel discharge distributions during peak.

vertical dashed line. The sequence of discharge distributions reveal the existence of a flood jet as hypothesized for the "offset jetties" geometry.

Analysis of the discharge distributions from the ocean to the bay (Line 4 to Line 1 on Figure 6) indicates that flood flow into Shinnecock Inlet evolves as follows:

Line 4: Flood flow entering the channel is concentrated to the left (west) of the entrance centerline with strongest velocities close to the flow separation line derived from inviscid theory (dashed line on Figure 5). Significantly less discharge is observed adjacent to the east jetty (right side of plot).

Line 3: A short way into the channel a majority of the flow is now located to the right (east) of the channel centerline, and flow along the east jetty (right side of plot) is accelerating as predicted by inviscid jet theory.

Line 2: This ADCP transect is over the deepest part of the scour trench adjacent to the east jetty toe (see bathymetry in Figure 8). The flow is definitely concentrated on the right (east) side of the channel, and the discharge distribution is very similar in shape to that of a turbulent wall jet. The effect of a growing boundary layer adjacent to the east jetty is also evident.

Line 1: Finally, as the flow exits the inlet channel, the flood jet shows considerable spreading due to lateral flow entrainment on the left side and boundary layer growth on the right. Velocities have decreased from the maximum values, and a little farther into the bay littoral sediment swept into the inlet will begin to deposit on the flood shoal. Notice the relatively minor discharge into the west channel (left side of Line 1 plot). During ebb tide, this west channel carries the majority of the flow as it exits the bay.

Vertical Velocity Distributions at Maximum Flood Tide

Figure 7 presents plots showing the vertical distribution of velocity magnitudes for selected profiles spaced along a transect line that closely approximates Line 2 shown on the Figure 5 plan view. These velocity data were collected around maximum peak flood tide on December 4, 1997, using a boat-mounted ADCP. The vertical profiles span the inlet throat, and they are more or less evenly spaced across the inlet with average spacing about 35 m (110 ft). Profile 4 is closest to the west (shorter) jetty, and Profile 44 is closest to the east jetty. Vertical profile 22 is located at about the channel centerline.

These vertical velocity distributions show how velocity magnitudes and depths increase in a crosschannel direction moving from the west jetty toward the east (longer) jetty. Maximum velocities on the order of 1.5-2.0 m/s (5.0-6.6 ft/s) occur in the vicinity of Profile 36, which is at a location about one-fourth of the channel width off the east jetty. In the

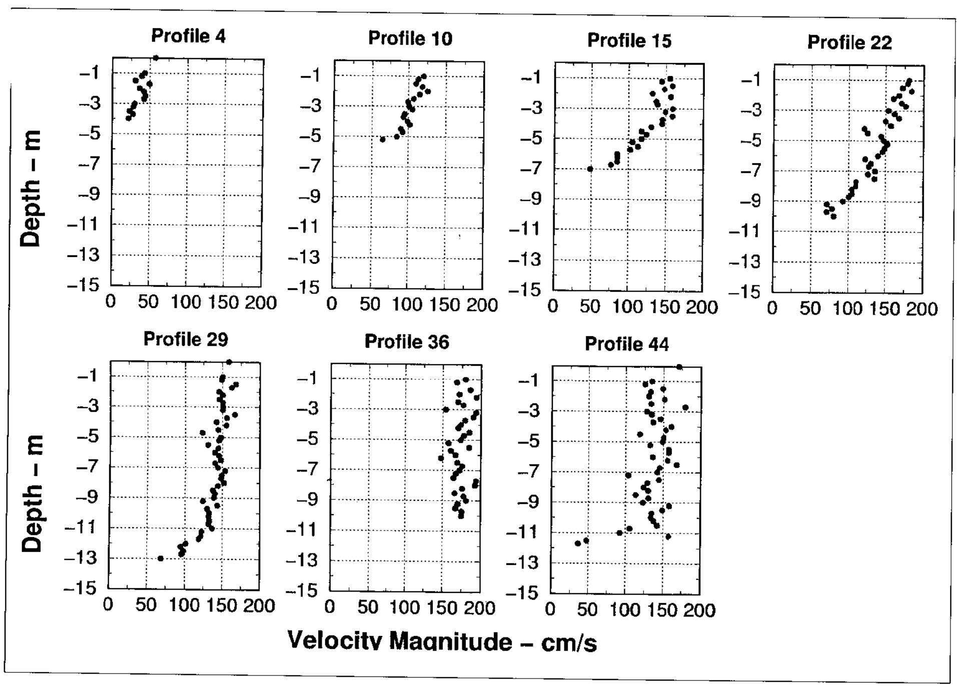

Figure 7. Vertical velocity distributions across Shinnecock Inlet during peak flood tide (December 1997).

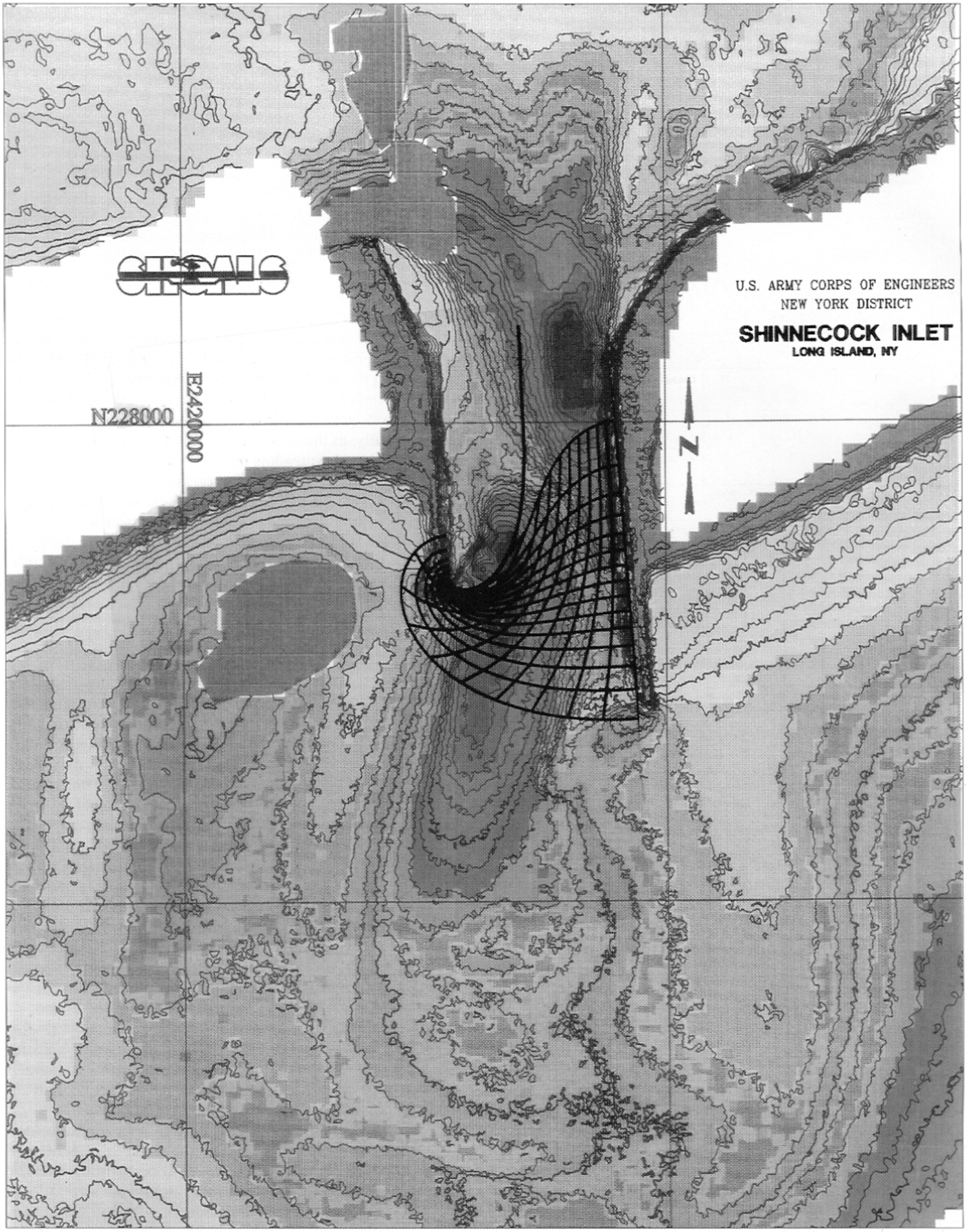

Figure 8. Shinnecock Inlet SHOALS bathymetry with inviscid jet flow net overlay.

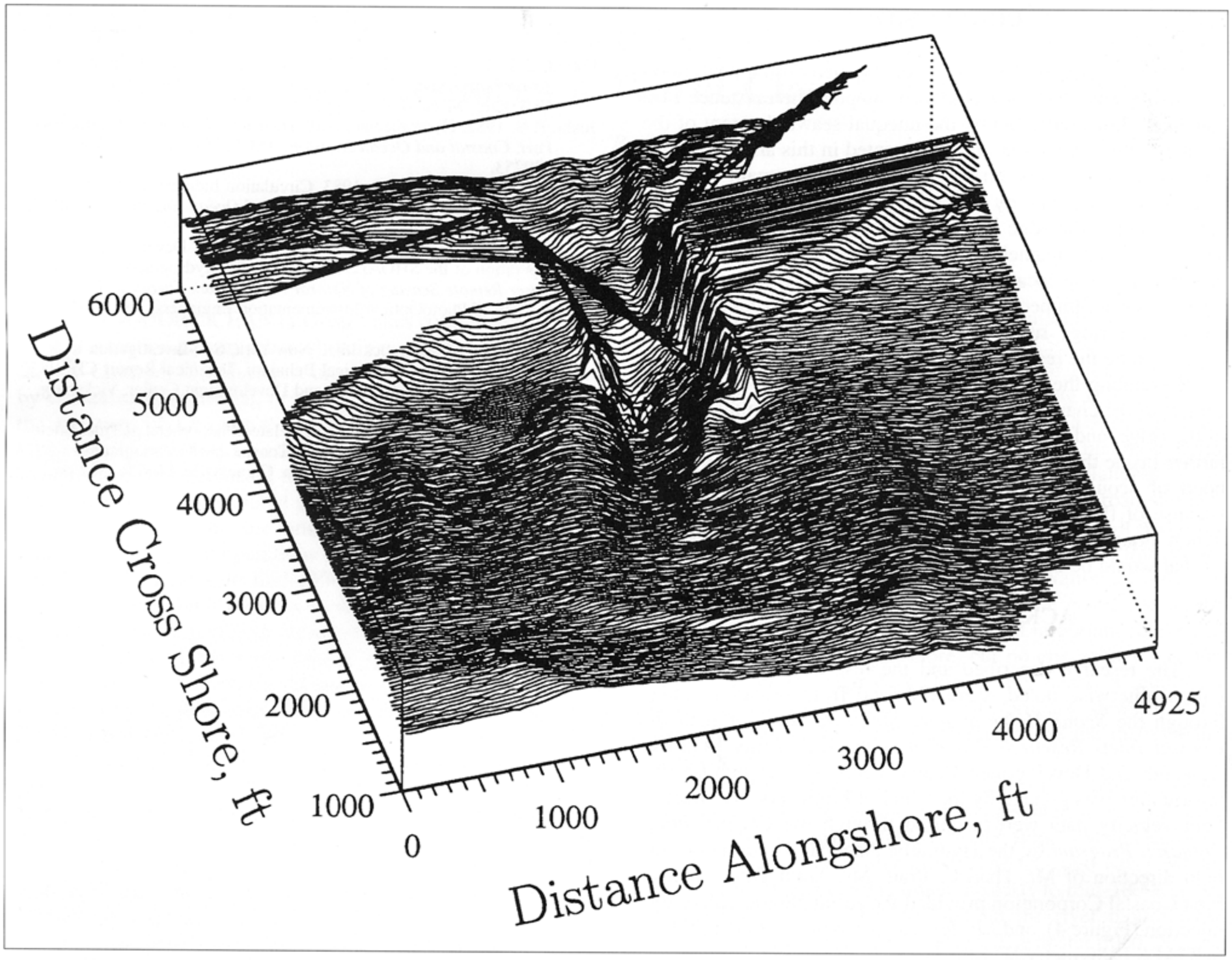

Figure 9. Oblique projection of Shinnecock Inlet scour holes.

ideal inviscid jet conceptual model, Profile 36 would be located near the center of the jet.

The vertical velocity measurements also clearly indicate that the velocity profiles typically exhibit a pronounced vertical variation similar to a fully-developed boundary layer extending from the bottom to the free surface. This is especially true in the turbulent entrainment region extending from Profile 4 to Profile 22.

Shinnecock Inlet Scour Holes

Two large scour holes persist in the Shinnecock Inlet entrance channel as shown in Figure 8. Bathymetry collected in 1997 using the SHOALS system (Lillycrop, et al. 1996) is shown with a flow net overlay developed using inviscid jet theory for an inlet nozzle with similar geometry. (The SHOALS system obtains bathymetric data through transmission and reflection of a laser beam emitted from a pod mounted on a helicopter or airplane.) The flow net shows streamlines crossed by lines along which discharge is constant. Notice that the deepest portion of the seaward most scour hole is in a region of the jet where the flow is rapidly accelerating and the streamlines are closely spaced. In addition, this may be a region with rotating flows due to flow entrainment into the jet or vortices associated with flow separation. Farther into the inlet, flow entrainment decreases the velocities near the outer edge of the jet while the flow continues to accelerate along the east jetty.

The scour hole along the east jetty near the landward end of the entrance channel (Figure 8) is probably caused by the ebb tidal flow at Shinnecock Inlet. Observations indicate that during ebb tide the majority of the flow exits from the western channel approach and crosses over to the east side of the channel, where it is then deflected seaward by the jetty. Fluid entrainment reduces the deflected ebb jet velocities resulting in decreased scour trench depth and width at the seaward end of the scour trench. The strong velocities of the flood flow jet probably contribute to maintaining the scour trench along the east jetty, but the flood currents are probably not the primary cause of the scour.

The vertically-distorted oblique view of the Shinnecock Inlet SHOALS bathymetry in Figure 9 illustrates more clearly the ridge feature separating the two scour regions. This ridge appears to be some type of scour "nodal point" between the flood and ebb jet scour regions. Along this ridge there is an uneasy equilibrium where sediment is deposited as the ebb and flood jet velocities are decreased by the effects of flow entrainment.

CONCLUSIONS

Current velocity measurements obtained during peak flood tide conditions at Shinnecock Inlet support the existence of a "jet-like" flow controlled by the unequal seaward extent of the parallel jetties. Although not documented in this article, a similar jet-like flow occurs during ebb tide when the main ebb flow is deflected seaward by the east jetty. In both cases, fluid entrainment at the edge of the jet spreads the flow distribution across the inlet channel while decreasing the mean velocities downstream. The location and platform configurations of the scour holes at Shinnecock Inlet conform to this hypothesis, and the distinct ridge running diagonally across the inlet throat appears to be the result of alternating flood and ebb jets.

Extending the west jetty should result in a flood jet more central to the channel, and this would probably eliminate some of the ridge, and perhaps reduce scour adjacent to the east jetty farther inside the inlet. However, there would be a strong likelihood of scour holes persisting near the tips of both jetties because of flow separation during peak flood tide. The scour trench along the east jetty appears to be dominated by the ebb jet that would be unchanged by extension of the west jetty.

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